Development and Implementation of an Interdisciplinary Course at the Interface of Chemical Engineering and Nursing

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Abstract

An interdisciplinary faculty team developed and implemented a course, "Clinical Immersion at Disciplinary Interfaces," involving upper division students from the Department of Chemical Engineering (CHE) and the Whitson-Hester School of Nursing at Tennessee Technological University. The course leverages a variety of on-campus initiatives focused on innovation-driven learning and entrepreneurship and is responsive to broader calls and challenges in that it seeks to better prepare graduates to respond to healthcare issues with safe, cost-effective, and sustainable technologies and approaches. A hallmark of the course is a clinical immersion experience in which interdisciplinary student teams visit different units in the local hospital where they are coached to look for opportunities for innovation. Ultimately, the teams are challenged to identify a problem (need), to generate ideas for ways to solve this problem, and to develop prototypes that are marketable and responsive to problems in healthcare at the interface of engineering and nursing.

Keywords

Interdisciplinary Teams, Innovation, Clinical Immersion, Nursing, Chemical Engineering

Introduction

National Calls for Innovation and Work at the Interface of Disciplines

The clinical immersion course and related activities described herein are at the interface of the chemical engineering and nursing disciplines. The logic for this particular "matching" of disciplines is built on many tenets that include national priorities and recognized synergies between engineering and nursing programs, among others. As one example, a bit more than a decade ago, the Board on Chemical Sciences and Technology in the National Research Council was tasked with identifying projected "challenges" that exist at the interface of the fields of chemical sciences and engineering. Such challenges, as presented in *Beyond the Molecular Frontier*[1] (the resulting publication), include the development of better drugs to treat disease and determination of the function of genetic sequences, among many others. Experts recognized the need to bring disciplines together for better outcomes, including health-related aspects such as modes of drug delivery and minimizing drug interactions. Over the last several years, there has been increased emphasis on "breaking down the silos" in higher education setttings. Interactions between engineering and nursing accomplishes the goal of cross-disciplinary collaboration and could be expected to enable the design of better drugs and delivery systems, as examples.

Both engineering and medicine think tanks have issued calls for innovation, and the National Research Council (including representation from the National Academy of Science, the National Academy of Engineering, and the Institute of Medicine) as well as the American Society of

Engineering Education (ASEE) are supporting efforts to document and emphasize the need for effective cross disciplinary communication and collaboration to improve outcomes. As one example, in a recent publication[2] addressing the substantial benefit associated with the convergence of experts from various disciplines in solving complex problems affecting society, the report's authors provided numerous examples of how such approaches are already having significant impact and provided recommendations for facilitating continued efforts. In the *Vision of Engineering in the New Century*[3] from the National Academies Press, ten attributes were espoused that the engineer working in the year 2020 should possess. Among traditionally-recognized attributes such as strong analytical skills, good communication skills, and high ethical standards, it was emphasized that the engineer must also possess attributes of creativity (invention, innovation, *etc.*) and business acumen. The TTU College of Engineering in fact has recently implemented a Renaissance Engineering model that seeks to graduate engineers that are adaptive, inquisitive, and creative[4]. A cornerstone of this effort from a pedagogical perspective is the Renaissance Foundry, a platform that emphasizes both knowledge acquisition and knowledge transfer in the form of team-based identification of needs and development of prototypes[5-6]. In both the College of Engineering and the School of Nursing at TTU, challenge-based learning in the form of Legacy Cycles[7] are implemented by the authors of this paper to engage students in idea generation and creative problem solving with a focus on real-world issues identified by instructors. As part of the clinical immersion course, the Legacy Cycle methodology is integrated with other activities to facilitate the identification of needs (*i.e.*, problems or opportunities) by the interdisciplinary teams of nursing and chemical engineering students instead of by the instructors. The associated transfer of knowledge within and across these disciplines might be expected to better prepare such students for the opportunities of tomorrow which likely will be very different than those today[8].

In 2010, the Institute of Medicine in *The Future of Nursing: Leading Change, Advancing Health*[9] emphasized the importance of standardization and innovation. Many hospitals are seeking "Magnet Status" in which evidence-based practice is paramount and the need for all members of the healthcare team to effectively communicate observations across disciplines is emphasized. Currently 423 hospitals (3 in Tennessee) have achieved Magnet Status from the American Nurses Credentialing Center (ANCC)[10]. Magnet hospitals excel in five key areas: transformational leadership; structural empowerment; exemplary professional practice; **new knowledge, innovations, and improvements**; and empirical outcomes. There is a tremendous shortage of nurses in rural communities[11]. Because nurses in high shortage areas are not provided the same orientation and mentorship experiences, they must be able to immediately transfer skills and knowledge to a wide variety of patient types. Training nurses who are adaptive and flexible in using knowledge will lead to increased patient safety and positive care outcomes. Further, the ability of nurses and other members of the healthcare community to function in multi-disciplinary teams has been recognized as an important aspect of providing high quality of care, and efforts to increase communication skills towards this goal are being pursued[12].

As yet another example of the variety of broad-sweeping initiatives that are occurring at the interface of disciplines, one could consider the grand challenges that have been issued for numerous disciplines. In February of 2008, the National Academy of Engineering (NAE) unveiled fourteen "***Grand Challenges for Engineering***", the result of a study commissioned by the National Science Foundation in an effort to guide policy and budget decisions and inspire a new generation[13]. At the news conference of the release, Dr. Charles Vest (President of NAE at the time) mentioned the anticipated synergy ("interdependence") that will exist between engineering, science, and medicine in solving the problems of the 21st century. Several of the challenges relate in some manner to the quality of human health, particularly the "***Engineer Better Medicines***" challenge which includes such activities as drug development and applications in clinical diagnostics.

Today's employers are stressing the important role of innovation in successfully competing in today's global market in which knowledge gaps are narrowing. Hospitals are expecting medical staff (nurses, physicians, etc.) to become "bedside inventors," identifying problems and proposing evidenced-based solutions in collaboration with other types of professionals (engineers, technicians, etc.). Dean Martha Hill, Johns Hopkins University, stated[14]:

> "Today, the lines are blurring, and it is in this middle ground that we may solve some of our toughest challenges. Whether we call these hybrids of the future bio-nursing engineers or bio-engineering nurses, their career opportunities will be limitless. They will research and develop systems of care, medical equipment, and technological procedures. They will bring the best practices of both professions to bear on evidence-based healthcare. And they will combine the nursing hallmark of patient-centered care with the principles of electrical, chemical, and mechanical engineering to improve health and the quality of life for populations across the lifespan and throughout the world".

Ultimately, the activities in the clinical immersion course are believed by the authors to be responsive to these broader calls and predictions. A brief summary of the CHE and nursing programs are provided immediately below to give a bit of context regarding the academic environment in which the course is offered, and this is followed by course details, results and discussion, lessons learned, and conclusions.

About CHE, Nursing, and Related Collaborations at TTU

The Department of Chemical Engineering at TTU is a rapidly growing program with more than 400 undergraduate and graduate students. The undergraduate program has two concentrations: one in chemical engineering and another in biomolecular engineering that requires that students take courses in biology along with a department-offered course in biotransport phenomena. Graduate students occasionally enroll in graduate courses in the TTU School of Nursing, particularly in areas of pharmacology and pathology. The School of Nursing is also a rapidly growing program that offers BS and MSN degrees, and recently has begun offering a doctoral degree in partnership with East Tennessee State University. Graduates from the programs pursue employment opportunities in the rural Upper Cumberland (UC) region of Tennessee, in large metropolitan areas, and a variety of other locations. The UC region is also the base for one of nine regional business accelerators (The Biz Foundry) that has close collaborations with faculty and students at TTU and is working to help build the entrepreneurial environment in the region. Immersing engineering and nursing students in a course that showcases the variety of devices and approaches that are used in healthcare and that also shed light on potential new opportunities that have not been recognized but that require expertise from multiple disciplines is a salient feature of the methodology chosen. Such efforts would ideally form the basis for new marketable products and start-up companies.

Course Details

Administrative Aspects and Enrollment
The three-credit hour course is referred to as "Clinical Immersion at Disciplinary Interfaces" and dual-listed as CHE 4973 and NURS 4990. It is co-taught by a Faculty from CHE and Nursing. The class meets at various locations in a single three hour block of time each week with each instructor being present for each class session. Eight upper division nursing students and six upper division chemical engineering students were enrolled in the course during the initial course offering (Fall 2015), and these students were divided into four interdisciplinary teams of three or four students (see Table 1) at the beginning of the semester.

Table 1. Disciplinary and Gender Distribution of Teams

	# Nurses		# CHEs	
Teams	Male	Female	Male	Female
A	1	2	0	1
B	0	2	1	1
C	0	2	1	0
D	0	1	0	2

The initial development of the course has been supported through funding from the TTU Quality Enhancement Plan that is focused on "Undergraduate Creative Inquiry", and expanded efforts (eventually also to other engineering disciplines) are being supported via a Faculty Grant to the authors from VentureWell and the Lemelson Foundation. Efforts in the course are focused on helping the teams to identify opportunities for innovation, to generate ideas for ways to respond to the opportunities, and to translate those ideas into prototypes that are built, tested, and showcased during on-campus innovation and entrepreneurial-focused events referred to as EagleWorks and Golden Impacts. In addition to the focus on idea generation and prototype development, efforts are being pursued to allow the authors to assess the influence of the interdisciplinary team-based activities on creative and critical thinking skills and other topics. Specifically, we are also interested in ultimately answering the following research questions:

1. What effect do interdisciplinary (chemical engineering/nursing) student teams have on the quality of ideas generated during a clinical immersion experience?
2. In what ways do interdisciplinary teams support the development of viable prototypes?
3. What similarities and differences exist in the communication styles of chemical engineering and nursing students?

Meeting Locations and Assignments/Assessments
Table 2 provides details about the meeting locations, activities, and times during the semester that the activities occurred or were expected to occur. As shown, a variety of facilities across campus and near campus were utilized depending on the specific activity being pursued. These locations included classroom and laboratory spaces in the buildings that house nursing and chemical engineering, an innovation studio/maker space (referred to as iCUBE) located in the library, the local (regional) hospital, and other demonstration sites. Assignments and/or assessment activities included completion of a teamwork contract similar to that used by Biernacki[15] to establish student responsibilities and team goals, a quiz to assess student content knowledge regarding congestive heart failure and based on instructor-led discussions and reading assignments, flowsheets intended to prepare students for the clinical experiences, a pre-post

Critical thinking Assessment Test[16], and a final presentation. Though three quizzes were initially projected, only one was completed as this item was ultimately deemed to be less important to the desired course and student learning outcomes. Additional activities are discussed further below.

Table 2. Course Meeting Locations, Activities, and Timing

Week	Meeting Locations	Activities
1	School of Nursing (SON) classroom and "fundamentals" lab	• Course introduction • CAT assessment (critical thinking) • Team building activities • Fundamentals lab (hospital etiquette/hospital equipment)
2	SON classroom and "simulation" lab	• Team work contract • 5-Why's for problem-solving • Content: Disease processes and fluid balance • Fundamentals lab (IV solutions, access devices, Swan-Ganz, Foleys) • Introduction of clinical flow sheet
3	Holiday	• No class
4	Cookeville Regional Medical Center (CRMC) including the ER, CICU, CV, and other units	• Clinical Immersion 1
5	iCUBE (an immersive facility located in the TTU library and utilizing virtual reality and maker space infrastructure)	• Virtual heart • ***QUIZ 1 (Heart failure, Coronary Artery disease, basics of access devices (PICC lines and central lines))*** • Windkessel model • Introduction to Legacy Cycle • ***Patho to evaluation or Medicine to evaluation flow sheet 1***
6	CRMC	• Clinical Immersion 2
7	CHE Teaching Lab	• ***QUIZ 2 (CHF, dehydration)*** • Content: Renal failure • Kidney in a box • Intro to Multiple Perspectives (What, Who, Why, How) • ***Patho to evaluation or Medicine to evaluation flow sheet 2***
8	Fall Break	• No class
9	Ambulance/paramedic training site	• Clinical Immersion 3
10	SON classroom	• Clinician – Devices for Urology • ***QUIZ 3 (Acute and Chronic Renal Failure)*** • ***Patho to evaluation or Medicine to evaluation flow sheet 3*** • Group meetings with faculty
11	Respiratory Therapy (RT) training room at CRMC	• Group presentation work • Devices used in respiratory therapy • Begin prototype development
12	No formal meeting location	• Prototype/Final presentation work/interviews with experts (Business/medical/nurses…)
13	No formal meeting location	• No official class – work on prototypes/presentations
14	No formal meeting location	• Team meetings with faculty • Time to build and work on Final Presentation
15	No formal meeting location	• CAT post-assessment • Team work contract evaluations • Final Presentations • Plan for Next Steps (competitions)
16	Final Exam Week (Note: Final Presentations serve this purpose)	

Fundamentals Lab (Etiquette/Equipment)

The fundamentals lab located in the School of Nursing contains a variety of simulators that represent life-sized representations of human anatomy and physiology. These include traditional manikins and low-fidelity simulators. Also, a variety of equipment (such as oxygen regulators, hospital beds, vital sign measurement devices, etc.) that would be found in a hospital setting is available. A simulation was run by the nursing instructor who intentionally demonstrated examples of proper and improper etiquette (*e.g.*, HIPAA violation, introducing oneself to the patient, patient dignity, ethical standards, etc.), and discussions ensued to emphasize appropriate behavior. Afterwards as a team building activity and to further emphasize proper etiquette, nursing and chemical engineering students participated in a series (relay race) of challenges such as changing a gown, putting on compression stockings (TED hose), placing a pulse oximeter, taking a blood pressure reading, and others. To aid the engineers in understanding and with the proper technique, a nursing student who was already familiar with proper technique was located at each station. The engineers and nurses then competed to see which group could complete the series of challenges first. This lab was particularly important in laying the ground for the clinical immersion experiences that happened later in the semester.

Fundamentals Lab (Devices)

This lab experience was designed to introduce students to numerous medical devices (*e.g.*, Swan-Ganz catheters, PICC lines, etc.) used in the management of fluid and electrolyte imbalance, a common pathology associated with a variety of diseases and pre/post-operative procedures. A graduate assistant from nursing, who currently works in the intensive care unit, showed the devices to the students and demonstrated how the devices are integral to patient care. The nursing students focused on the practical use and data obtained by the devices, while the engineering students asked questions about device design and placement in the human body. Successful outcomes and cautionary examples were provided to further emphasize the importance of these devices and their proper design and use. Later in the semester when students were in the clinical setting, they were better prepared to ask questions to patients, families, and nurses concerning these devices.

Kidney in a Box Experiment

In this experiment, cell culture inserts (Becton Dickinson, number 35-3090) along with other components described further below and illustrated in Figure 1 were used to simulate aspects associated with filtration and reabsorption in the kidneys. This filtration occurs at the interface between the glomerulus (a capillary bed in nephrons) and the Bowman's space (a fluid reservoir that connects to the tubule system in the nephrons) while the reabsorption occurs through a combination of passive and active transport processes in the tubules. The activities commenced with small balloons that were each filled with about 50 ml of water. Each student received a balloon, and a small hole was carefully punched through the balloon wall. The students gently squeezed the balloon to force the water out of the balloon and into a collection bucket. The time to completely release the water was measured, and flowrate from each experiment was calculated (assuming that each balloon actually contained 50 ml of water). Flowrates typically were in the range of 50-100 ml/min. Students were coached to carefully observe the rate of flow from each balloon. As glomerular filtration rate (GFR) is the rate at which the kidneys filter the blood (and a typical value is 125 ml/min), this simple demonstration gives students a visual representation of GFR. In actuality, each kidney contains about one million nephrons, thus total GFR reflects the combination of flows through all the nephrons.

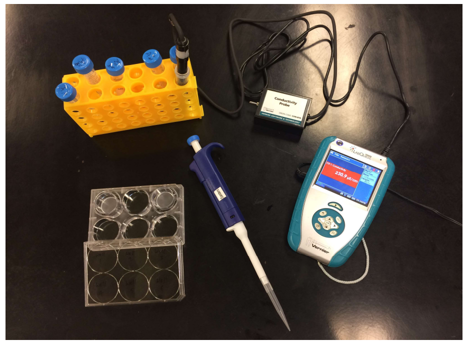


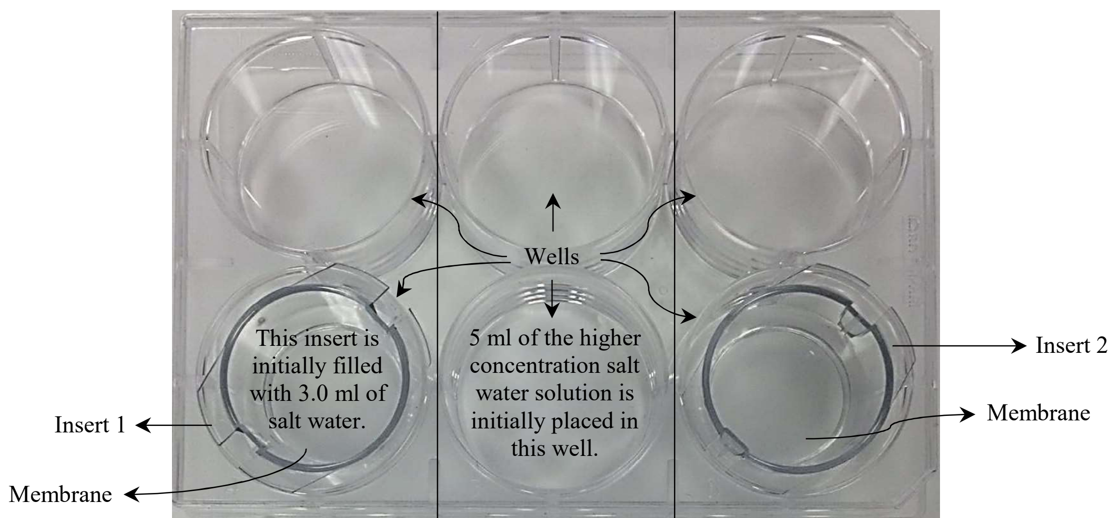
Figure 1. Components of Setup for Kidney in a Box

Next, the interdisciplinary teams each completed a set of three experiments designed to simulate 1) filtration through glomerular walls and into the Bowman's space, 2) water diffusion (osmosis) through the descending limb of a nephron, and 3) ion (*e.g.*, Na+, Cl-, etc.) transport through the ascending limb of a nephron (see Table 3). The inserts were used along with water and salt water solutions (at room temperature and at concentrations of 0.125 and 0.5 mg NaCl/ml water), Vernier LabQuest hardware, and conductivity probes (vernier.com) as detailed below (also see Figure 1) to yield results in-line with those expected from actual transport in the kidneys.

Table 3. Focus Areas, Expected Results, and Limitations of Kidney-in-a-Box Experiment

Experiment #	Anatomical Focus	Physiological Focus	Expected Results	Limitations
1	Glomerulus-Bowman's space	Filtration through the glomerular walls and into the Bowman's space.	Conductivity of the salt solution that is filtered in Experiment 1 should be relatively unchanged from that of the original stock.	Cellular-type materials and proteins are not included in the experiment though latex beads and discs as simulants for cells and/or proteins could be used.
2	Descending limb of a nephron	Water diffusion (*i.e.*, osmosis) through the descending limb of a nephron.	The solution remaining in the insert at the end of Experiment 2 should have a higher concentration (conductivity) than that of the solution which was filtered.	The descending limb is not highly permeable to ions, but in our studies there is no particular means to prevent net transport of salt from the high salt solution to the filtrate (*i.e.*, the fluid remaining in the insert).
3	Ascending limb of a nephron	Ion (*e.g.*, Na+, Cl-, etc.) transport through the ascending limb of a nephron.	The conductivity of the solution collected from the insert at the end of Experiment 2 should decrease as the solution equilibrates with water placed on the opposite side of the membrane.	The transport of salt out of the ascending limb occurs through an active transport process, while in our studies the mechanism of transport is passive, down a concentration gradient into water sitting in the bottom of the well. The ascending limb is impermeable to water, but in this simulation, water migrates down its concentration gradient through the membrane.

In Experiment 1, an insert is placed into a well in a 6-well plate, and 3 ml of the 0.125 mg/ml salt water solution is added to the insert (see Figure 2, left). Filtration occurs due to the weight of the fluid on top of the porous membrane, but often times the cohesive forces prevent this process from occurring quickly. When filtration is not occurring (which is typically the case), the bottom of the membrane is gently wiped with a finger to break the tension and enable the flow. The solution then filters through the membrane until none is remaining in the insert (normally taking about 20 minutes). During the filtration, after flow has decreased, the insert is often lifted slightly to complete the filtration process, as the pressure exerted by the fluid in the well on the bottom of the membrane results in a pressure equilibrium that otherwise prevents continued net flow through the membrane. Conductivities of the original 0.125 mg/ml stock solution as well as of the filtrate are measured with values expected to be on the order of 250 µS/cm (measured at ~290 µS/cm for each). As salts and water molecules are very small relative to the size of the pores (0.4 µm) in the membrane and also the glomerular wall, these molecules travel relatively unimpeded through the pores revealing similar conductivity values. Size exclusion-type phenomena could be demonstrated as well if larger molecules (and structures to simulate cells) were used with the salt water solution, though this experimental aspect has not been examined.



Experiment 1: Nothing is initially placed in the bottom well shown above, but the "lower" concentration salt water solution filters through the membrane (at the bottom of the insert) and into the well over a period of time.	Experiment 2: The insert that was used in Experiment 1 is moved to the bottom well shown above, and the solution that filtered through the membrane in Experiment 1 is reloaded into the insert after its conductivity is measured.	Experiment 3: The solution remaining in the insert at the end of Experiment 2 is transferred (after its conductivity is measured) to a clean insert located in this bottom well which initially contains 5 ml of water.

Note: The bottom row of wells are used for these experiments.

Figure 2. Graphical representation of the experimental procedure.

In Experiment 2, the filtrate from Experiment 1 is pipetted back into the insert which is then placed (see Figure 2, middle) in a well in the 6-well plate that has been pre-loaded with 5 ml of the higher concentration (0.5 mg/ml) salt solution (conductivity expected to be on the order of 1000 μS/cm and measured at ~1140 μS/cm). The inside of this insert including the membrane are used to simulate the descending limb. The volume of the higher salt water concentration solution that is used is such that the level of fluid is expected to be approximately the same on both sides of the membrane in an effort to minimize any hydrostatic pressure gradients in the system. By visual inspection, the volume of fluid in the well is adjusted if necessary to ensure that the fluid levels are approximately equal. After a period of time on the order of 10-20 minutes, the experiment is stopped at which point the fluid in the insert is collected as is the fluid in the well. Conductivities for both are then measured. The expectation is that water in the filtrate will travel down its concentration gradient downward into the well (which simulates the tissue) and that salt will travel down its concentration gradient upward into the insert. Thus, the net effect is that the solution in the insert is expected to become more concentrated while that in the well would be expected to decrease. This is in fact what happens with conductivities after 15 minutes expected to be on the order of ~410 μS/cm and 1,060 μS/cm for the insert and well, respectively. Since the concentration of salts increases *in vivo* as the filtrate travels through the descending limb (as the nephrons are attempting to recover water that has been filtered), the increased conductivity of the fluid in the insert simulates the change that happens *in vivo* though the relative contribution to the water efflux and salt influx have not been quantified. A limitation of this aspect of the study is that the descending limb is relatively impermeable to salts.

In Experiment 3, the solution collected from the insert is then placed in another insert which is then positioned in a well that has 5 ml of water added (see Figure 2, right). The inside of this insert including the membrane are used to simulate the ascending limb. As for Experiment 2, the volume of the fluid in the well is chosen to ensure that the fluid levels on both sides of the insert are at about the same level with water being removed from the bottom well as necessary to be certain that this is the case. Again, after a period of 10-20 minutes, the experiment is stopped at which point the conductivities of the fluid in both the insert and the well are measured. The expectation is that the salt in the insert will travel down its concentration gradient into the well and that the water in the well will travel down its concentration gradient upwards into the insert. The conductivity of the fluid in the well goes up as any salt migrates there and as water leaves (with a value of ~40 μS/cm, up from 10-15 μS/cm for the water alone). Whether the conductivity of the insert fluid goes up or down is controlled by the relative rates of water influx to the insert and salt efflux from the insert. A typical value expected for the conductivities would be on the order of 370 μS/cm (based on a measurement at 15 minutes). While the salt in the descending limb actually leaves via active transport processes, the decrease in the salt concentration in the insert simulates the expected decrease in salt concentration of the fluid in the ascending limb, though a limitation of the study is that the ascending limb is actually impermeable to water.

While conducting these experiments, the nursing and chemical engineering students each contributed valuable feedback to the others. The engineering students showcased their knowledge in using the Vernier systems and the detection modalities as well as their understanding of fluid mechanics and mass transfer. Likewise, the nursing students demonstrated their expertise regarding transport processes in the kidneys. Both groups had familiarity with osmosis which greatly aided the teams' collective abilities to predict the results. For follow-on activities, the "low" salt concentration solution could be made isotonic with blood and the "high" salt concentration solution could be made hypertonic. Then when conductivity readings were made, the sensor would be saturated, and the samples would have to be diluted.

Virtual Reality and Maker Space

The iCUBE (Imagine, Inspire, Innovate) facility at TTU has a virtual reality space that incorporates a small-room, boxed environment in which special goggles are used in visualizing and interacting in virtual space. One model that is currently in place is that of a human heart. Students in the class were able to "step inside" the heart and experience the structures (*e.g.*, chambers, vessels, chordae tendineae, etc.) in an immersive three dimensional manner. Before coming to iCUBE, the students learned about congestive heart failure (CHF) and read an article about an innovative artificial heart design. This background knowledge gave the students a starting point to understand cardiac structure and changes that occur during CHF. The facility also has a maker space that includes 3-D printers, metal and wood cutting machines, equipment for the development of sensing devices and much more. Students participated in a tour of the facility and were encouraged to use the facility for making their prototypes.

Clinical Immersion Experiences

The hallmark of the course involved three clinical immersion experiences (two in the local hospital and one at the community college paramedic training site which is located on the TTU campus). In the hospital, the nursing and engineering teams paired with a registered nurse (RN) on the assigned unit. The teams rotated units (ER week 1/ICU week 2, for example) each week. Prior to the clinical immersion days, the students completed Confidentiality Agreements, HIPAA training, and training concerning disease transmission/infection control as well as immunization requirements. The Faculty instructors provided the students a list of questions to consider on the unit (Table 4) and encouraged the students to talk to all stakeholders (*e.g.*, nurses, respiratory therapists, physical therapists, patients, families, etc.). A retired industrial engineer rotated among the groups during the clinical immersion to help the students as they explored opportunities and generated ideas.

Table 4. List of Questions for Teams to Ask Healthcare Professionals during Clinical Immersion

1. How are the vital signs measured? (pulse, HR, Blood pressure, Oxygen saturation, pain level)
2. What is a COW?
3. Do you think the vital signs that are documented are accurate for your patient? (Do the vital signs correlate with the clinical appearance?)
4. How is fluid status monitored?
5. Find a patient with a tube (Nasogastric tube, G-tube, colonostomy, chest tube, foley catheter….) , drain (surgical drain, t-tube), or dressing. Ask the patient about it (what does it feel like? Is it painful? Do you think it is doing its job?). Ask the nurse about it (how do you care for it? How do you know it's working? What do you document?)
6. Is a patient going for a diagnostic test? Ask if you can go with the patient. Ask the nurse or xray tech about the test (why are they doing it? What would be a good result vs. a bad result?, how is the test performed? Are there restrictions—certain people or devices that would mean the patient can't have the test?)
7. Does the patient have an IV? What type of fluid is running? Why that particular fluid? What is the infusion rate? Why that rate?
8. Watch a nurse through the entire med administration process.
9. Watch a nebulizer breathing treatment. What medications are used? How would RN or Respiratory therapist know it worked?

The third clinical immersion experience focused on pre-hospital medical care. The Director of the Emergency Management Services Program at the local community college presented trauma simulations with high fidelity simulators. Another part of this clinical day was a demonstration of devices used in an ambulance. This clinical day demonstrated to the students the differences between emergent pre-hospital care and the inpatient experience. Both the nursing and engineering students commented on the number of devices stored in the ambulance as well as how small changes in design and protocol resulted in big changes in health outcomes (*e.g.*, a Combat Application Tourniquet). It is interesting to note that the engineers as well as the nurses became quite captivated with the mechanical structure of the simulators. The paramedic instructors took the simulators apart to show the students the various compressors, pumps, and sensors needed in the high fidelity simulators.

Results and Discussion

Assignments/Assessments Overview

Expectations for all students in the course were the same. Nursing and engineering students were given the same assignments and participated in all of the same activities, however, both individual and team-based performance were considered in the overall grading process. Pre-requisite knowledge was very important in the process, but this was somewhat mitigated based on the fact that the focus was on fluid balance and this information was presented in such a way that both nurses and engineers at the junior/senior level would have adequate background knowledge. In some cases, content was provided by the instructors to fill perceived gaps, and students were challenged to communicate their perspectives to each other.

Teamwork Contract

A teamwork contract was completed by each team in an effort to make certain that each team member understood his or her roles on the team and to emphasize the importance of working together. The contracts included such items as individual team member responsibilities and team goals. Engineers had worked in teams much more often in several of their previous classes and were already familiar with the teamwork contract which aided the process.

Quizzes

On the one quiz that was given, each student first completed the quiz on his or her own using one color of ink, and after a period of time, the students assembled into their teams and compared their responses to the quiz prompts. During these discussions, each student made adjustments and/or additions to his or her initial responses using a different color ink and then turned in their finalized responses. One of these quizzes was selected by each team to be graded by the instructors. One observation noted by the instructors regarding differences in communication between nurses and engineers was that the engineers often responded using diagrams while the nurses responded using lists.

Flowsheets

Flowsheets provided a means for teams to prepare for the clinical immersion experiences. Everyone was expected to contribute in teams to complete the flowsheets to ensure that all were adequately prepared for the clinical experiences. The knowledge and input from the nursing students was a key factor in completing these flowsheets as the information was largely focused on physiology and healthcare.

CAT Assessment

The Center for Assessment and Improvement of Learning at TTU administers the Critical thinking Assessment Test (CAT) which has been developed by investigators at TTU and collaborating sites with funding from the National Science Foundation[16]. The test examines four general skills associated with critical thinking including the ability of the test takers to: evaluate information, to think creatively, to solve problems, and to communicate effectively. Each student completed this test on the first day of class and again on the last day of class just before the team presentations. These data will be scored by an independent group of trained scorers and the aggregate results made available to the authors for further analysis and use in examining the effects of the course activities on improving critical thinking and guiding changes to the course.

Reverse Legacy Cycle (Final Presentations and Related Activities/Milestones)
On the last day of class, each team presented information about the various opportunities for improved healthcare delivery that had been identified, including the final one that the team selected and why a particular one was chosen. Teams also presented details regarding the prototypes developed and provided a summary of the overall process that was pursued. The instructors had provided a template for the teams to reflect on the process undertaken to identify a problem and implement a solution methodology to complete the projects.

Regarding the prototypes, these were designed, built, and tested to varying degrees by each of the interdisciplinary teams, and two of the prototypes are currently being further developed. Some of the prototypes may form the basis for intellectual property in the form of patents, thus, only general statements regarding these are made below. One prototype represents a new approach to shielding radioactivity. Though ionizing radiation is not an aspect of MRI scanners as it is for other imaging modalities (*e.g.*, x-rays, CT scans, etc.), interestingly this team had the opportunity to visit with a patient before he was to undergo an MRI. Another prototype reflects a modification of a Peripherally-Inserted Central Catheter (PICC) line with a very novel application. This group observed that as the cost of inpatient treatment increases, patients are being discharged with these venous access lines in place. At home, this increases certain risks. Another team prepared a sensor-based system for monitoring patient elevation. This team had an interaction with a healthcare provider utilizing one of the technologies listed in the table. The other team identified a very interesting combination technology.

During the course activities, a variety of technologies were demonstrated by the clinical instructors during each of the clinical immersion experiences. This established and expanded a knowledge base for the students and also provided an indication of the appropriate level of complexity that the teams should focus on for their prototypes. A sampling of pictures of these technologies is provided in Table 5 which also includes an indication of the complexity of the technologies based on the authors' collective assessment. The scoring system used by the authors ranked the technologies on a scale of 1-5 with a score of 1 corresponding to a relatively simple device and a score of 5 indicating a highly complex system. The target level for the prototypes was in the 2-3 range which would likely be the most complicated that could possibly be expected for a 15-week semester.

Throughout the clinical immersion experiences, the instructors routinely heard students asking questions about approaches. For example, a student would ask a healthcare provider specific questions such as "are there devices that you work with that could be improved?" The instructors also asked questions in efforts to shed light on opportunities. For example, an EMT professional was asked to comment on the most significant change that he had seen in the back of an ambulance. His response was that now everything that is done is based on evidence, thus supporting the important and complementary role of both knowledge acquisition (as an example in the form of basic research) and knowledge transfer (as an example in the form of technology development and commercialization). Along the way, opportunities were identified by the teams, and each can be directly related to devices that were observed and handled.

Table 5. Example Technologies/Devices Demonstrated

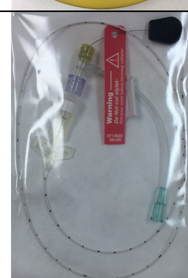
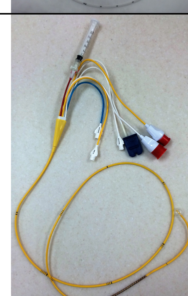
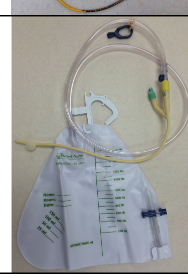
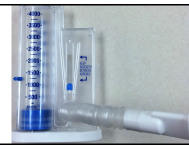
Technology/Device	Description	Image or Link	Relative Complexity*
Compression Stockings and Socks	Help with circulation to legs and feet		1
Gowns	Provide improved access for patient vitals		1
Bed Pans	Volume collectors for bed-bound patients		1
Peripherally-Inserted Central Catheters (PICC)	Venous access devices for rapid administration of drugs and/or contrast agents		3
Swan-Ganz Catheter	Measurements of pulmonary arterial and wedge pressures; fluid delivery		3.5
Foley Catheter with Bag	Used to drain the urinary bladder; sometimes also used to drain the pleural space during pleural effusion		2.5
Flutter Valve	Helps to ensure airways stay open (often used with incentive spirometer)		3.5

Table 5 Continued

Incentive Spirometer	Helps to ensure airways stay open (often used with flutter valve)		3
Codman Drain	Helps to regulate pressure in the space between the brain and skull	[17]	3.5
Combat Application Tourniquet	Rapid and complete stoppage of blood flow	[18]	2
Emesis Bags	Notched container that is used to collect and contain vomit in an ambulance or other location	[19]	1.5
Wolf-Tory Mucosal Atomizer Device	Used to atomize medications for delivery to the nasal mucosa	[20]	2
IV Pumps	Used for highly controlled delivery of fluids and medicines		3.5
Hospital Beds	Designed to control patient elevation and comfort		4
Ventilators	Used for facilitated or total respiratory support	[21]	5
Scanners for Magnetic Resonance Imaging (MRI)	Used to visualize tissue with high resolution and contrast	[22]	5

*Represents an average of scores from the nursing and chemical engineering co-instructors.

Lessons Learned

There have been many lessons learned from the initial offering of the clinical immersion course. For example, we learned that the teams need to be provided opportunities to visit the clinic as early in the semester as possible. There were many opportunities identified by the student teams, but providing sufficient time to brainstorm ways to solve the problem, to build prototypes, and test them necessitates getting started with these activities sooner. We initially envisioned more focus on content associated with the chosen domain (fluid balance) in the body, but we also realized that if this topic is carefully selected, then students bring much of this information to the class already. Also, structured debriefing sessions after the clinical immersion experiences is important to help students decompress from the physically and emotionally taxing environment of a hospital. Moving forward, we would also envision restructuring quizzes and flowsheets to more directly assess communication styles as this is one of the primary areas of research focus of the investigators.

Conclusions

An interdisciplinary course has been developed and offered for the first time during the Fall 2015 semester at TTU that seeks to involve chemical engineering and nursing students in an immersive environment in which students from one discipline are exposed to those in the other. The efforts are focused on helping the resulting interdisciplinary teams to identify opportunities for innovation and to develop prototypes that are responsive to challenges in healthcare at the interface of the two disciplines. Such efforts are responsive to a variety of calls for innovation and solutions to grand challenges. Follow-up efforts will focus on continued development of the devices towards commercialization as appropriate, assessments of changes in critical and creative thinking as well as communication skills, and continuous improvements of the course with expansion to include other engineering disciplines.

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